

our prodigal sun

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Cover photo: Overlapping spectroheliograms capture wavelengths of several solar elements on single strip of special film. Bright complete sphere is ionized helium. Ejected arch of helium, top, hangs suspended 800,000 km (500,000 miles) into corona.

our prodigal sun

Not only our lives but also our way of life depend upon the Sun. Nearly all energy available to us is or was created by solar energy. Coal, oil, and gas that have fueled the expansion of our civilization were made from plants that acquired their energy by converting sunlight. Even the winds that drive windmills originate from uneven heating of our atmosphere by the Sun. Waterpower is dependent upon rainfall which is possible only because the Sun's heat evaporates water standing on Earth. Trees and other plants from which man and animals obtain energy collect that energy from sunlight.

There are only three nonsolar sources of energy; geothermal (heat from Earth's interior); tidal (the rise and fall of the tides because of the Moon's gravity pull); and nuclear. Nuclear energy is presently derived from atomic fission, the splitting of atoms. Nuclear fusion, which generates the hydrogen bomb's awesome destructiveness, can potentially provide tremendous energy for mankind if it can be controlled. Nuclear fusion is considered the source of the Sun's energy.

The world needs new, economically attractive, non-polluting energy systems as alternatives to dwindling reserves of oil, gas, and coal. A recent study by the National Science Foundation and NASA has concluded that practicable solar energy systems could reach substantial levels of public use within 10 years. NASA is contributing to a number of applications of solar power to meet man's needs on Earth.

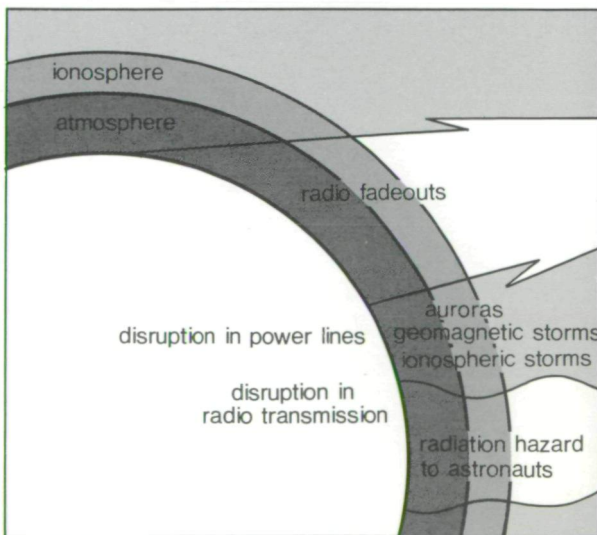
The Sun will last another five billion years in its current state as a normal, or main sequence, star. So, solar power may be considered inexhaustible. And no one can cut off our imports of sunshine.

The Sun may be considered prodigal in its generation of energy. Every second, it throws off into space more than man has used since civilization began.

About one two-billionths of this reaches Earth. In three days, this tiny fraction of the Sun's energy provides about as much heat and light as is available from all our known reserves of coal, oil, and gas.

Man studies the Sun, therefore, because it is a major source of present and potential future energy as well as the source of life on Earth. Man also studies the Sun to learn more about the Earth's weather and climate. How changes in solar activity influence these is not yet completely understood. However, it has been observed that a slight variation in the Sun's output of energy could melt the polar icecaps, submerging coastal areas, or could bring on another ice age.

From time to time, enormous solar eruptions hurl vast clouds of matter and intense lethal radiation into space. The inhabitants of a craft traveling in interplanetary space would be endangered if in the path of such a cloud, but the atmosphere and geomagnetic field protect life on Earth. However, the power of this cloud is revealed to mankind in many ways.

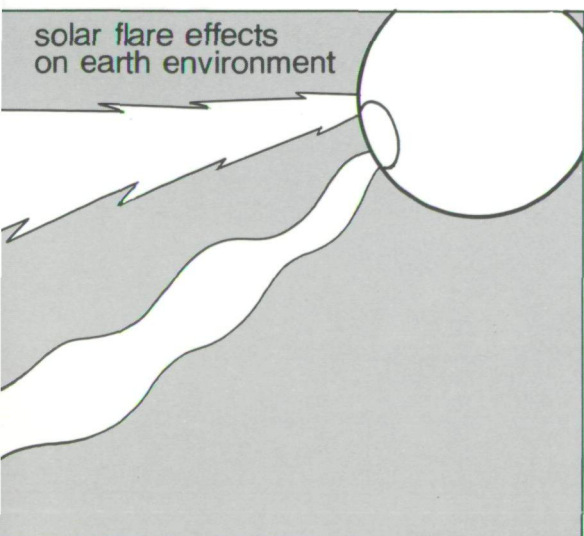


For example, auroras light up the night skies over the far northern and southern latitudes of Earth. Compass needles on ships and airplanes may swing erratically. Electric power transformers may trip out, and long distance radio, telegraph, and telephone communications, black out. Engineers want to know how to predict such eruptions as a step toward avoiding the problems they cause.

From the standpoint of physicists, the Sun is a laboratory where temperatures, pressures, and magnetic field intensities can be studied at magnitudes impossible in laboratories on Earth. The Sun is also the astronomer's bridge to the study of other stars. The more he knows about the Sun, which is the only star close enough for him to study in fine detail, the more he can use it as a reference point for understanding what is happening on other stars. Conversely, many other stars are like our Sun but in different stages of their evolutions. These then picture the past and future of our Sun.

what makes the sun shine?

Scientists generally agree that nuclear fusion is the source of energy of the Sun

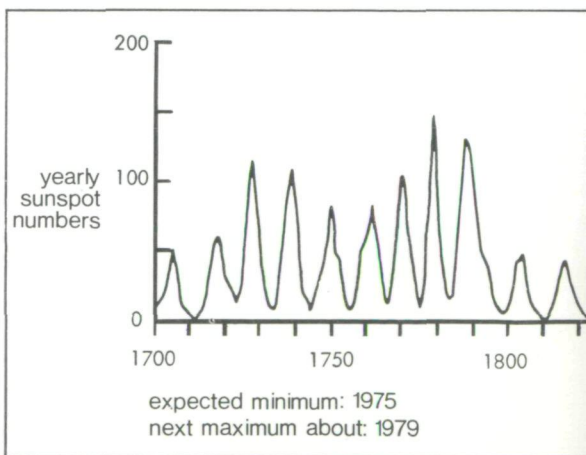


and most other stars. Deep within the interior of the Sun, temperatures are approximately 16 million degrees Centigrade (25 million degrees Fahrenheit), and pressures, 70 trillion grams per square centimeter (a trillion pounds per square inch). It has been calculated that a pinhead of material at the temperature of the Sun's core would emit enough heat to kill a man a hundred miles away.

Under these pressures and temperatures, four hydrogen atoms are believed to fuse into one heavier atom of helium. But the atomic weight (a relative number, computed in relation to a standard weight of 16 for an atom of oxygen) of hydrogen is 1.008; of helium, 4.003, leaving a discrepancy of 0.029, about 0.7 percent, between the helium nucleus and the four original hydrogen nuclei. The disappearing mass has been transformed into an equivalent amount of radiant energy in accordance with Albert Einstein's famous equation $E=mc^2$ showing the interchangeability of matter and energy. (E is energy; m, mass; and c, the speed of light.)

If the immense energy released at Sun's core reached its surface in the form of gamma rays as originally created, the result would be a death ray fanning through the solar system from a dark Sun.

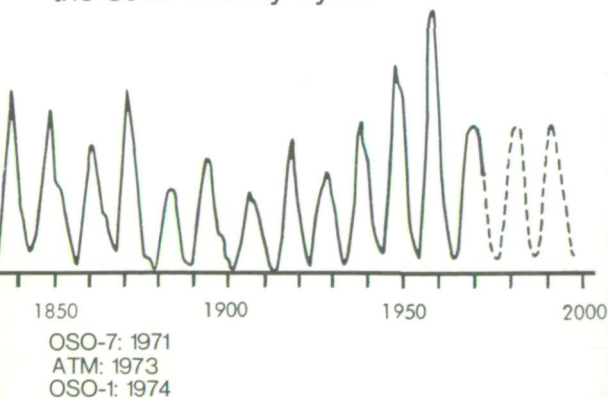
Gamma rays have the highest frequency (shortest wavelength) of any electro-mag-



netic radiation. Electromagnetic radiation is radiation that is electrical and magnetic in nature, as differentiated from nuclear particle radiation such as protons and electrons. From their highest to the lowest frequencies, wide bands of electromagnetic radiation have been designated gamma rays, X-rays, ultraviolet rays, visible light, infrared rays, and radio waves.

All electromagnetic radiation travels at the speed of light, about 300,000 kilometers (186,000 miles) per second. But the path of the electromagnetic radiation generated in the Sun's core is so tortuous that the radiation takes 20,000 years or more to reach the surface. On its way up, it continually collides with and bounces from closely packed protons, electrons, and other solar particles. In these collisions, its energy is gradually dissipated, and its frequency steadily drops. As a result, by the time it speeds from the Sun, much of it has turned to infrared radiation (heat), visible light (sunshine), ultraviolet light (the part of solar radiation that causes your skin to get a sunburn), radio waves, and X-rays. So, the sunbeams that warm and brighten our world today "originated" 20,000 or more years ago, before the time of recorded history. But the same sunbeams took only about 8½ minutes to streak from the Sun's fiery surface to Earth.

the solar activity cycle



our rhythmic sun

The number and size of sunspots (dark areas on the Sun) wax and wane through an 11-year rhythmic cycle. Solar activity rises and falls in harmony with the appearance of sunspots. Sunspots appear to be composed of gases boiling up from the Sun's interior and are frequently accompanied by intensified emission of all forms of radiation.

Sunspots are actually bright and hot. Their temperatures, for example, are typically 4200 degrees Centigrade (about 7600 degrees Fahrenheit) which is hotter than a blast furnace. However, they are cool and look dark compared to the surrounding photosphere (the bright visible disk of the Sun) with 5700 degrees Centigrade (about 10,300 degrees Fahrenheit).

A small spot may be roughly the size of Earth. Larger ones may be big enough to hold hundreds or thousands of our planet. (The Sun itself contains about as much mass as 330,000 Earths, and its volume is about 1,300,000 times that of Earth.)

Strong local magnetic fields appear at the sites of sunspots. Most violent outbursts of solar material such as solar flares seem to derive their energies from these magnetic fields.

strange rotation

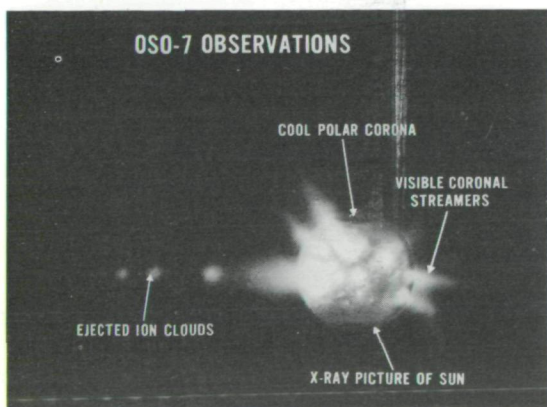
The Sun is a churning everchanging ball of hot gases. Because it is gaseous, it need not rotate uniformly at all latitudes. Observations indicate its equatorial regions rotate around the Sun's axis every 25 days while the area around either pole may take as long as 33 days. Other areas have periods of rotation between those of the equator and pole. This uneven rotation distorts the Sun's magnetic field and may cause sunspots and contribute

to such additional peculiarities as reversed polarity (the North and South magnetic poles trading places) near the peak of each solar cycle. Other variable solar features probably are related in some way to this contorted rotation.

solar poles and coronal holes

Comparatively cool polar areas were discovered on the Sun in 1971 through NASA's Orbiting Solar Observatory (OSO) 7. Electronic measurements indicated that the poles have a temperature of about 1 million degrees Centigrade (about 1.8 million degrees Fahrenheit) compared to other parts of the Sun's corona, or outer atmosphere, that generally register 2 million degrees Centigrade (3.6 million degrees Fahrenheit). Cyclical variations in the sizes of the caps appear to correspond with solar activity, with the caps smallest at the peak of a solar cycle.

In 1973, the solar observatory on NASA's Skylab space station confirmed that the so-called polar caps were not limited to polar areas. Similar conditions—cooler and more rarified gases than the surrounding areas—occur elsewhere on the Sun. Astronomers call them coronal holes. The holes were found to extend into the uppermost part of the chromosphere (the layer



of several thousand kilometers between the photosphere and the corona) where temperatures are only about 50,000 degrees Centigrade (90,000 degrees Fahrenheit). Astronomers don't know why the chromosphere is different in these holes. Some believe that the holes may give new clues to the solar interior.

Skylab data also showed that magnetic fields in the coronal holes stretch outward rather than arch back to the Sun. Scientists speculate that the holes may be the source of the solar wind, the hot electrified gas particles (mostly protons of hydrogen atoms) constantly rushing outward from the Sun to as far as the orbit of Pluto. The solar wind is considered by many to be part of the Sun's corona, which means the Sun's atmosphere engulfs the whole solar system.

the wind from the sun

NASA Explorer, Mariner, OSO, and Pioneer spacecraft confirmed the existence of and have provided much new information about the solar wind. The spacecraft also indicated that wind temperatures are hundreds of thousands of degrees and wind velocities hundreds of thousands of kilometers per hour. The wind's heat and speed vary with solar activity. The wind more closely resembles a rocket blast than any other thing we know about on Earth.

The solar wind draws out parts of the Sun's magnetic field. But the Sun's rotation together with the radial outward motion of the solar wind twist the drawn-out magnetic lines of force like streams of water from a whirling lawn sprinkler.

why is the corona so hot?

Heat dissipates with distance from its source. Temperatures also drop with distance from the Sun's core, where thermo-

nuclear reactions are taking place, to its surface. One would expect the temperature in the Sun's outer atmosphere to be even cooler. But instead, temperatures climb from several thousand degrees in the coolest part of the atmosphere to several million degrees in the corona. Why the corona heats up is not definitely known.

Some astrophysicists believe that the seething bubbling granules at the Sun's surface break like ocean waves, creating a thundering roar. As this sound rushes upward into more rarified gas, it accelerates, eventually creating supersonic shock waves that heat the gases to high temperatures.

the mystery of the disappearing granular structure

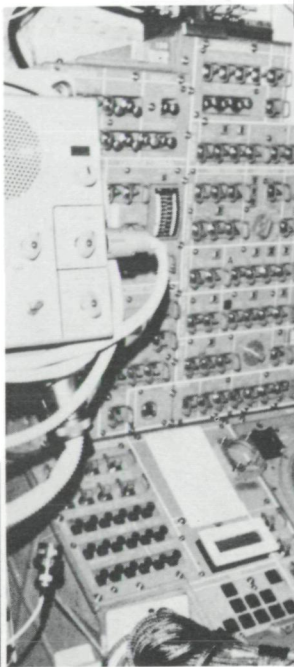
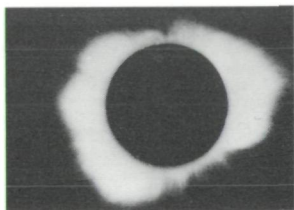
The granular structure poses mysteries too. In the photosphere, it is a fine structure with irregular cells typically a few thousand kilometers in diameter. In the chromosphere, cells are about ten times larger in diameter. Skylab showed that this granular structure persists through the chromosphere into the lower corona ($300,000^{\circ}$ Centigrade). Then, at the 1.5 million $^{\circ}$ C level, it has suddenly become smeared and nearly disappears. The significance of this is not understood, but it seems that the "super" granules are somehow related to coronal heating. This will be studied with OSO-I (eye) in 1975.

prominences

Skylab data indicated that prominences (condensed streams of hot luminous gas rising from the Sun) erupt more frequently than astronomers expected. Prominences appear to spring from sunspot groups. Their arched shapes indicate they are controlled by strong magnetic fields.

A prominence, which is made up mainly of ionized hydrogen atoms, is typically about a hundred times as dense as the corona. It sometimes rises at speeds of

Astronaut Edward G. Gibson at solar experiments console during Skylab mission. In solar eclipse, below, corona becomes visible as glowing area surrounding Sun. Close-up of Sun, bottom right, shows bright active regions.



hundreds of kilometers a second but usually forms a vast bridge of glowing gas hundreds of thousands of kilometers along its curved length.

solar bright spots

Solar bright points have been described as standing out on an X-ray image of the Sun like stars against the night sky. Sometimes, they have been called "mini-active regions". This term is scorned by some astronomers but is more or less justified by the occasional flaring observed on some bright points. These small flares have been termed "miniflares". Skylab pictures show the bright points are scattered all over the Sun, even in the coronal holes. This contrasts with the active regions near sunspots which are confined to a narrow belt extending 40 degrees north and south of the solar equator, where most violent activities take place. (Observations in X-ray wavelengths reveal the hottest parts of the Sun.)



solar flares and coronal transients

A solar flare is the sudden release of tremendous energy and material from the Sun, usually from a plage (the light area bordering a sunspot). A flare may last minutes or hours. It is marked by a sudden brightening.

A flare can erupt with the force of a billion hydrogen bombs. If the Earth were not protected by a strong magnetic field and the atmosphere, a flare's radiation could destroy all life. Its heat, if concentrated on Earth, could melt Earth's polar ice caps. One solar flare may release as much energy as the whole world uses in 100,000 years. Skylab showed that solar flares sometimes arch back to a different area of the Sun and trigger new flares at these areas. Scientists had suspected but never observed this before Skylab.

Skylab observations demonstrated that the solar corona is much more dynamic (changeable) than many believed. One of

the violent events that Skylab identified in the corona was a great explosion—called a coronal transient for want of a better name—that hurled outward enormous loops of material, hundreds of thousands of tons in weight, at speeds of millions of kilometers per hour. Such explosions also reshape magnetic fields and structural features in large parts of the corona.

the birth and death of the sun

With all of the new solar data pouring in from spacecraft, the Sun is proving more complex than ever. But the answers to many questions may be hidden in the data now on hand.

On one subject, however, most scientists seem to agree: how the Sun was born and how it will die. They have even calculated how much longer it has to live: five billion years as a normal, or main sequence, star.

Astronomers hold that the Sun and planets formed from an enormous contracting cloud of dust and gas. All parts of this cloud did not move uniformly. Some parts formed local condensations that eventually became our planets, moons, comets, and asteroids.

Gradually, the main cloud tended to become spherical. Gravitational contraction increased its temperature. Eventually the core temperature rose to a point where its hydrogen nuclei began to fuse. Nuclear energy then produced enough outward pressure of heated gas to balance the inward force of gravity and maintain the Sun as a glowing main sequence star. This is believed to have begun about five billion years ago.

About five billion years from now, the Sun will have depleted the hydrogen fuel in its core. Its thermonuclear reactions will then move outward where unused hydrogen exists. As it does, the tremendous nuclear heat at its core will also move

outward, expanding the Sun as much as 60 times. As the Sun cools by expansion, its surface color will become a deep red. It will then be a Red Giant—not a main sequence star. Looming across much of our sky, it will boil off our water and air and incinerate any remnants of life.

When the Sun exhausts its hydrogen fuel, it will no longer be able to withstand gravitational contraction. Eventually, it will shrink to a white (hot) dwarf, no bigger than Earth, but so dense that a piece the size of a sugar cube would weigh thousands of kilograms. Eventually, after billions of years more, our Sun will cool and dim to a black cinder. Only then will eternal night fall upon the solar system.

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